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Review Article

Change the Properties of Materials. Phase-Related Materials with an Emphasis in Mechatronics

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Abstract

A classification of phase-bound materials is made, their properties are determined and methods for obtaining the charge. They are considered to be species technological processes for production of phase-connected materials. Special attention is paid to their application with an emphasis in mechatronics.

Keywords: Phase-related materials; Technological processes; Application

Introduction

Classification and physical properties

Binding materials are subdivided into:

- for connecting separate layers (bimetallic pairs, springs)
- for connection between particles of different materials (powder metallurgy, electrical contacts of elements and compounds Ag/CdO, Ag/SnO_2, Ag/ZnO, sintered magnets, magnetically sensitive flat elements, nozzles, fluid distributors and connection of metallic and non-metallic components in artificial formed structure - toners for copying and printing equipment and control grids - Figure 1) [1]. The method of powder metallurgy is used to make contacts, gears, friction products - bearings and bearing units, bushings, levers, handles for household fittings, permanent magnets, weft guides and many others.

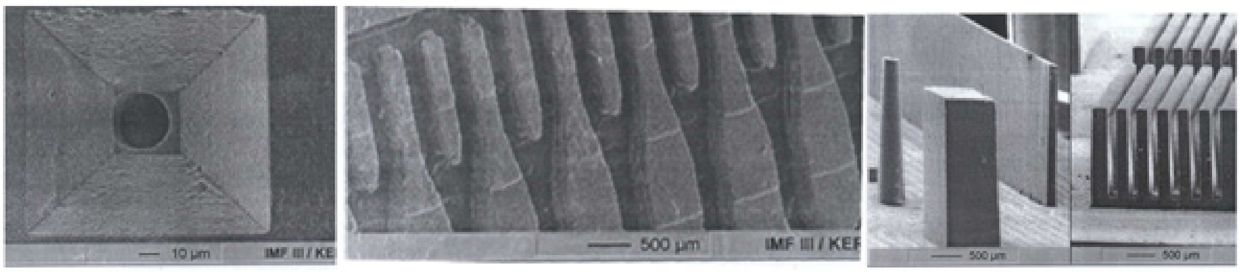

Figure 1: Zirconia nozzle, alumina fluid distributor and zirconium and alumina microstructures with high coefficient.

- for connecting individual parts (infiltration of sintered materials with high melting temperature with metals with low melting temperature in electrical contacts, for example from combinations Wo-Cu, WoC-Ag, WoC-Cu, Wo-Ag);
- for phase bonding, which in turn are subdivided into metallic compounds (Fe, Ni, Wo, steel), non-metallic inorganic (Br, SiC, Al_2O_3, glass) and organic compounds (carbon-based artificial materials, cellulose) and materials with mixed structure (metals, ceramics and organic substances such as graphite and epoxy resin) (Figure 2) [2].

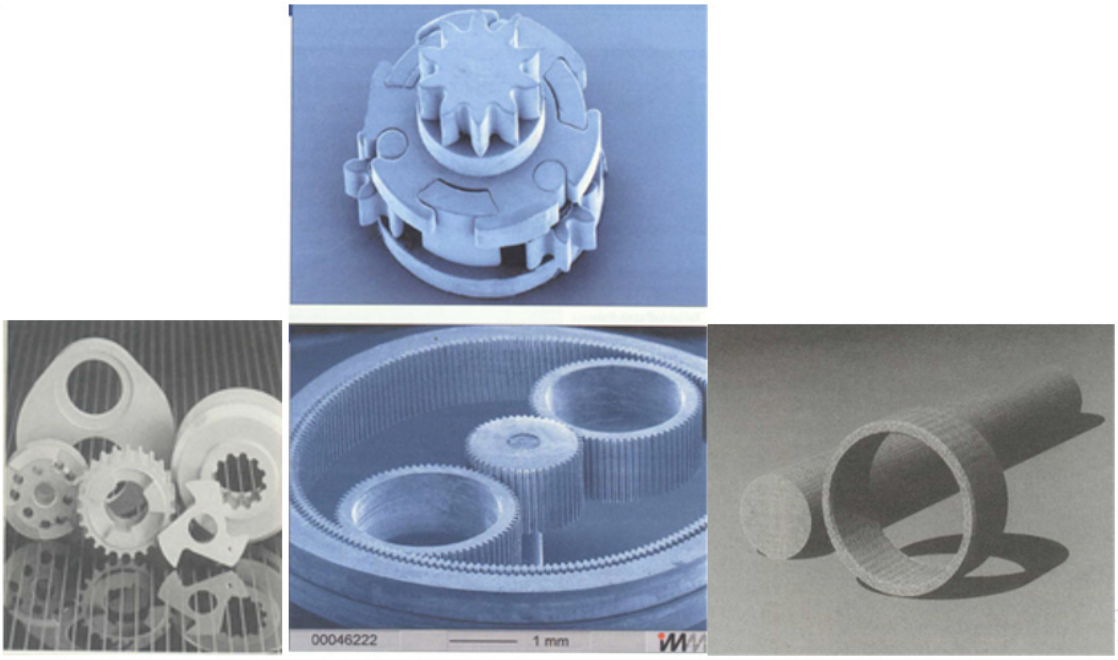

Figure 2: Details sintered from steel and bronze (left), phenolic resin (right), planetary gear from ROM and microharmonic gear from NiFe metal composite and $MoSi_2$ powder.

The properties of phase-bound materials depend on the properties of the particular combination and their structure. The first summarizes the properties of the individual components and those of the part (product). In table 1 the parameters of the more important materials are presented.

Table 1: Parameters of phase-connected materials.

Material	Density, g/cm³	Tensile Strength (Bending), N/mm²	Modulus of Elasticity, N/mm²
Canvas in the shape of a mat	1,45	160	12500
Canvas with three-dimensional structure	1,72	268	22000
Canvas with multilayer structure	1,93	526	33000
Fiberglass (S-glass)	2,50	3100	88000
Aramid fiber	1,0 - 1,4	3600	130000
Standard carbide	1,80	3500	220000
Special carbide	1,80	5600	300000 - 500000
Boron and silicon carbide	2,00 - 3,00	3500	400000
Borsilicate glass	2,31	-	64000
Especially borsilicate glass	2,28	-	64000
Electric glass	2,25	-	68000
Ceramics (Al2O3)	3,99	500	380000

Note: Characteristics of sintered materials and manufacturability of details of them are indicated in [3].

The production of details by the methods of powder metallurgy (sintering) is the most popular method [3]. The essence of the method consists in pressing powder from one metal or mixtures of several components with subsequent firing, and its foundation dates back to 1927 by Sobolevski in Russia [4,5]. By choosing the composition of the powder - the figurative mixture called the charge, you can get materials with predetermined properties, as well as to put additional reinforcing and non-metallic inserts. Materials that can only be obtained by this method include hard alloys, composites of metals and non-metals, porous materials. With the help of so-called metal ceramics, details with exact dimensions can be obtained, as the mechanical processing is shortened or completely eliminated. The products are susceptible to all kinds of coatings, as well as heat treatment, welding and soldering. The accuracy of the diametrical dimensions corresponds to H11 - H10, and in height - to H12 - H14; with final calibration the accuracy can be increased to H9 - H7. The quality of the surfaces is: roughness R_z = 20-6.3 μm, accuracy IT8 - IT12. A characteristic feature of the products of powder metallurgy is their porosity p, which ranges from 40-90%.

Basic Thesis

Materials Modification

The technological process and the properties of the details depend on the properties of the charge (material or shihte). The methods for obtaining it are divided into two groups:

- mechanical - crushing and vortex crushing, spraying, granulating and cutting:
- physico-chemical - chemical reduction, electrolysis of aqueous solutions, thermal dissociation of carbonates, electroerosion, intergranular corrosion and condensation.

In mechanical methods, the material is crushed without changing its chemical composition. The charge is obtained in vortex mills, where metal pieces, wire, shavings are used as starting material or by leaking a thin jet through a calibration hole, which is broken by inert gas (argon, nitrogen) or water. In physico-chemical methods, conversion is performed, and the charge (shihte) differs in composition from the starting material. These methods can be combined, for example electrolysis and beating in ball mills.

The main properties of the charge (shihte), which are given in the reference literature [3], are:

- bulk density and bulk weight - weight per unit volume in g/cm³:
- bulk fluidity - the ability to fill mold. i.e., the speed of pressing or flowing the charge (shihte) through a certain hole for 1 time in g/sec:
- particle size distribution - sieving through sieves and weighing of the obtained mass;
- compressibility - the ability of the charge to compact, fill the shape and maintains its transmitted form under the action of pressure forces;
- particle shape - the shape, size and surface of the particles are determined under a microscope.

The rule for mixing phase-bound materials is based on the required modulus of elasticity E_c, which must be obtained with the new composite. In case of purely elastic deformation of the material and the lattice, the modulus Ec is determined by the formula:

$$V_c E_c = E_F V_F + E_M V_M, \qquad (1)$$

where V_c is the volume content of the phase-bound composite, %; E_F - modulus of elasticity of the first, connecting component, N/mm²; V_F - volume content of the first component, %; EM - modulus of elasticity of the second, basic component, N/mm²; V_M - volume content of the second component, %.

Example:

Silver = 75000 N/mm², Steel=180000 N/mm², Ec = 130000 N/mm² at 36% by volume of steel.

In the case of plastic deformation of the lattice and elastic deformation of the joint, the modulus of elasticity of the phase-bound ECB material is calculated by the formula:

$$E_{CB} = E_{F.} V_F + d\,\sigma_M/d\,E_{M.}\,V_{M.} \qquad (2)$$

The new composite must always contain a certain volume of binder (fiber). Below this value, the gain of the parts depends only on the quantitative parameters and not on the properties of the fiberboard. The minimum volume of the required fiber Vmin is calculated:

$$V_{min} = (\sigma_{BM} - \sigma_M)/(\sigma_{BF} - \sigma_{BM} - \sigma_M) \qquad (3)$$

The properties of the structure are considered to be the properties that determine the shape, size and location of the individual components. Examples of different types of braids in phase-connected fabrics in the form of a single-layer mat, volumetric and multi-layer structure are given in Figure 3.

To determine the electrical properties, the specific resistance of the new composite in the transverse and longitudinal directions is calculated $\rho_{transversely}$ and $\rho_{longitudinally}$, respectively in series and parallel connection, according to the formulas [3]:

$$\rho_{transversely} = \rho_1 V_1 + \rho_2 V_2, \qquad (4)$$

$$1/\rho_{longitudinally} = V_F/\rho_1 + V_M/\rho_M. \qquad (5)$$

Technological processes for production of phase-connected materials

Production of details by cold pressing (sintering): The technological process for the production of details consists of operations: preparation of the charge; mixing; dosing; pressing; baking; calibration; heat treatment; additional mechanical processing; soaking in oil; coating (galvanic); other operations if necessary.

The mixing of different powder materials in certain proportions takes place in vibrating or drum mixers. For better mixing of materials with different relative weight, 1-2% glycerin, gasoline or alcohol is added, and as a plasticizer - 0.3-0.6% paraffin, stearin or artificial rubber dissolved in gasoline 7-10% of the mass of the charge. Dosing by volume is more convenient. Oxidation losses (3%) and combustion of impurities (0.6%) must be taken into account during dosing.

Dosing is performed by weight or volume. It is calculated by the formula:

$$G_{in\ bulk} = \chi . V_{detail}(1-p/100)\kappa \quad (6)$$

$$V_{in\ bulk} = \chi/\chi_{in\ bulk} V_{detail}\ (1-p/100)\kappa \quad (7)$$

where $G_{in\ bulk}$ is the weight of the required charge (shihte), g; Vin bulk - the volume in cm3; V_{detail} - the volume of the part, cm^3: p - the set porosity, %; k - the coefficient, characterizing the losses during pressing and firing (k = 1.04); $\chi_{in\ bulk}$ - bulk specific weight, g/cm^3; χ - the specific weight of the whole charge (shihte), g/cm^3.

The pressing consists of the stages: dosing and pouring into the mold, pressing and separating the part from it. It is performed on hydraulic or eccentric presses, the former being preferable due to the gradual increase in pressure, which results in a tighter adhesion of the particles and stronger contact between them. The pressing force is determined by the formula:

$$P = q . F . n . N, \quad (8)$$

where q is the specific pressing pressure, depending on the type of material from 100 to 1000MN/m2, F - the pressing area equal to the horizontal projection of the part, m2; n - the number of sockets on the mold, count.

When pressing, a uniform density of the part must be ensured; otherwise, internal stresses arise. It can be done unilaterally or bilaterally. The one-sided one is used for making simple configuration details, observing the ratios h/D ≤ 1 and h/b ≤ H (h - height of the part, d - diameter of the hole, b - wall thickness), and the double-sided pressing - at h/d ≤ 5, h/b ≤ 20.

In the complex shape of the parts, uniform density is achieved by using several self-moving punches instead of one or by pressing two transitions. The density (porosity) distribution p corresponds to the compression force and is shown in Figure 4. for one- and two-sided compression.

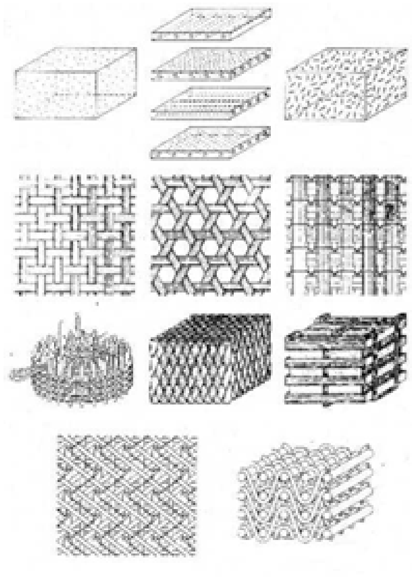

Figure 3: Arrangements of the braids in phase-connected materials.

Figure 4: Density distribution and tool - mold. Details [5].

There are two variants of cold pressing:

- by pressure
- to the point.

The height of the part is determined by the formula:

$$H_{detail} = h_{nominal}\ 100/(100 - \varepsilon + \varepsilon_{el.}), \quad (9)$$

where $h_{nominal}$ is the nominal height, mm; ε - relative shrinkage, %; $\varepsilon_{el.}$ - relatively elastic extension, %. $\varepsilon_{el.}$= 1.8 - 2.9 % at a specific pressure in the range of 1140 - 4000 kg/cm^2.

The power to remove the part $P_{eject.}$ is 20-25% of the pressing force P. It can be calculated by the formula [10]:

$$P_{eject.} = 0.4.\ f.\ Q\ F1, \quad (10)$$

where F_1 is the friction surface bay ejection, cm^2; f - coefficient of friction.

After removing the part, under the influence of internal stresses it expands, which phenomenon is called elastic aftereffect. It is several times larger in the direction of compression than in the transverse direction and depends on the density. At a density of 90% the effect is 5% in the longitudinal and 1% in the transverse direction. The forces of elastic aftereffect and those of pressure are opposite, which is the reason for the appearance of transverse cracks during removal. Therefore, the die is beveled at a height of 5 - 30 mm and at an angle φ = 10-30'.

To increase the physical and mechanical properties of the obtained parts are subjected to firing. The operation is performed in gas or electric furnaces and in a protective and reducing environment (hydrogen, ammonia). Re-pressing and baking or hot-pressing can be used to increase the density. The firing mode depends on the size of the blanks and the material and is performed in three stages:

- heating to a temperature of 100-200° C, at which the moisture in the charge is deposited;
- heating to half the firing temperature, which removes internal stresses;
- final heating to the firing temperature $T_{f.}$, which results in quasi-complete adhesion of the particles. Temperature $T_{f.}$ is defined:

$$T_{f.} = (0.65 \div 0.75)\ T_{m.}, \quad (11)$$

where $T_{m.}$ is the absolute melting point of the main component in the charge, K.

After firing, the blanks are subjected to calibration in order to obtain accurate dimensions of the parts and increase the degree of roughness of the surfaces. This operation is introduced with greater shrinkage and is performed by comprehensive pressure on the part. The shrinkage of the linear dimensions can be positive and negative, which depends on the composition of the charge, for example for iron powder with graphite up to 45% - negative 1-2%, and for iron with cast iron - positive 2-3%. The high-friction parts are impregnated with oil heated to 110-180° C before calibration for 2 hours. To increase the physical and mechanical properties of the parts (blanks) can be subjected to various heat treatments - cementation, nitro cementation, nitriding, boring, sulfidation, hardening or application to the surface of metallic galvanic coatings, especially chrome plating [6]. Other operations shall be applied as appropriate.

The tools for making details by the methods of powder metallurgy are called molds. According to their connection with the press, they are mobile and stationary. The mobile ones are used in single production, and the stationary ones - in serial and mass production. Higher productivity is obtained when making details of automatic and semi-automatic molds, which are single-nested and multi-nested in terms of the number of sockets. The main details of a mold are died, punch, ejectors and are made of alloy steel HVG, SHX15 and others with hardness after hardening HPC = 58-62. The clearance between the die and the punch is usually selected on the g6 assembly. Shrinkage and calibration allowance must be taken into account when calculating the working dimensions. The working surfaces of the details are polished to a mirror finish. In Figure 4 the schematic diagram of a single-acting mold for a part sleeve is shown. Other methods for obtaining details by cermets are Hot pressing and rolling of metal powders [7].

Technological processes for production of specific species details by phase-bound materials: The technological processes for the production of other phase-connected materials in mechatronics are mainly divided into [8-11]:

- direct (for existing semi-finished products)
- indirect (for the production of materials in a single process).

Direct processes, in turn, are divided into:

- method for production of canvases reinforced with phase-coupled composites.
- method for production of light guides from phase-connected materials.

The production of reinforced sheets with phase-bound composites is carried out in combination with the operation of plasma injection. The semi-finished product of phase-bound material is covered with foil, on which a layer of powder with a certain structure is applied by plasma jet. Figure 5 explains the principle of operation in the production of sheets reinforced with phase-bonding material. On the right is a picture of plasma injection molding on silicon carbide [12].

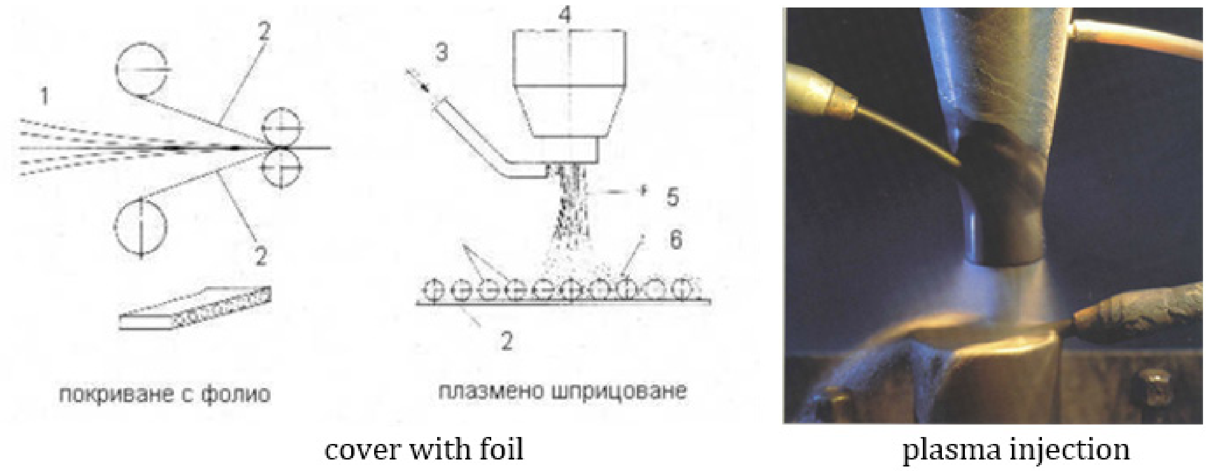

Figure 5: Production of reinforced canvases by plasma injection molding.

Hollow parts reinforced with phase-bonded materials can be assembled by explosive welding. Figure 6 shows the operations in the method of production of optical fibers, and on the right are given examples of optical fibers and cables for light from fiberglass [13]. The indirect method is designed to change the shape of threads wrapped with a common sheath (bundles). The making of the bundle itself is done by purposefully hardening the eutectic mixture. The mechanism of hardening and pulling through nozzles is given in Figure 6.

Technological processes for the production of optical fibers from phase-coupled materials with short fibers: The technological process for their preparation consists of the operations (Figure 7):

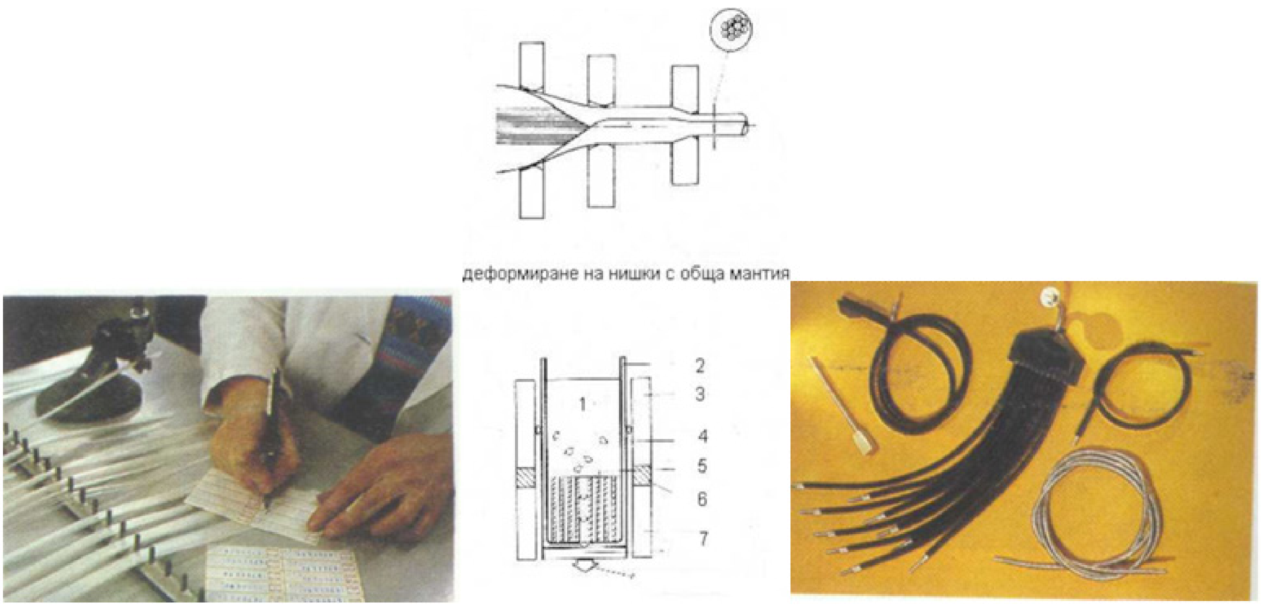

Figure 6: Pulling and hardening of a bundle of phase-connected material.

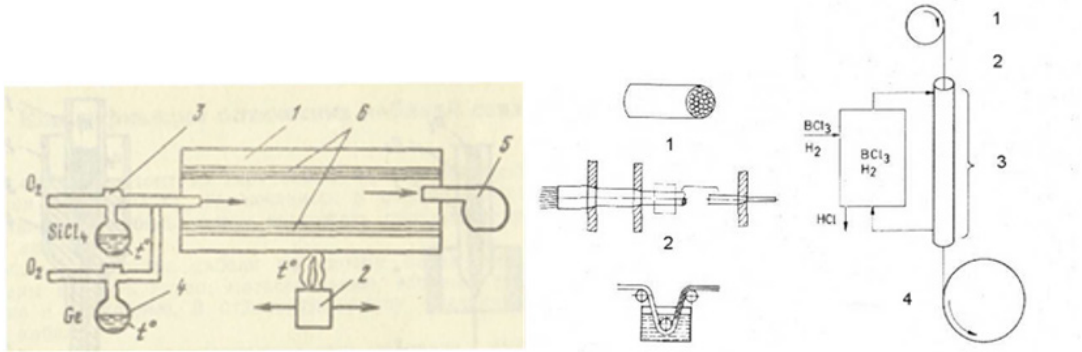

Figure 7: Chemical precipitation in the gas phase. Legend: 1-support tube, 2-heater, 3-chlorinated quartz, 4-germanium, 5-suction, 6-precipitated layer. Pulling continuous fiber through nozzles. Legend: 1-output combination, 2-deformation. Chemical reaction for the production of pine-based composite fiber Legend: 1-spool for feeding, 2-tungsten thread, 3-reaction zone, 4-spool for winding the thread.

- release into gaseous medium
- reduction of metal halogenides
- electrolyte deposition.

Example of reduction (substitution) of a metal halide: after chemical coupling, the halide is evaporated at a temperature between 400 and 900° C and reduced in a gaseous medium with oxygen. The resulting metal condenses on the wall of the reactor chamber, settles and can be collected. The so-called W-type optical fibers with double optical shell and dispersion of about 1.3 µm are obtained [14,15].

Production of thin optical fibers: The technological process for the production of very current thin, continuous fibers for light guides and waveguides includes the operations:

- solid plastic deformation
- chemical reaction
- deformation in the liquid state.

Solid deformation is carried out by the method of conventional drawing through nozzles, often called in the specialized literature "Brunswick"-method [16]. The resulting minimum diameter of the drawn fiber is determined by the superior properties of the material for the purpose and the transition transitions and reaches 5 µm. To remove the plaque, the fiber is rolled through a liquid. Figure 7 shows the principle of plastic deformation in the solid state.

A prerequisite for carrying out the chemical reaction in the production of continuous fibers from phase-bonded pine-based composite is the substrate of tungsten fibers and their heating to a temperature of 1100o C in an electro-resistive manner. The reaction is the thermal replacement of boron in a hydrogen environment and is often in practice called a chemical reaction (CVD method) by the formula:

$$2BCl_3 + 3H_2 = 2B + 6HCl \qquad (12)$$

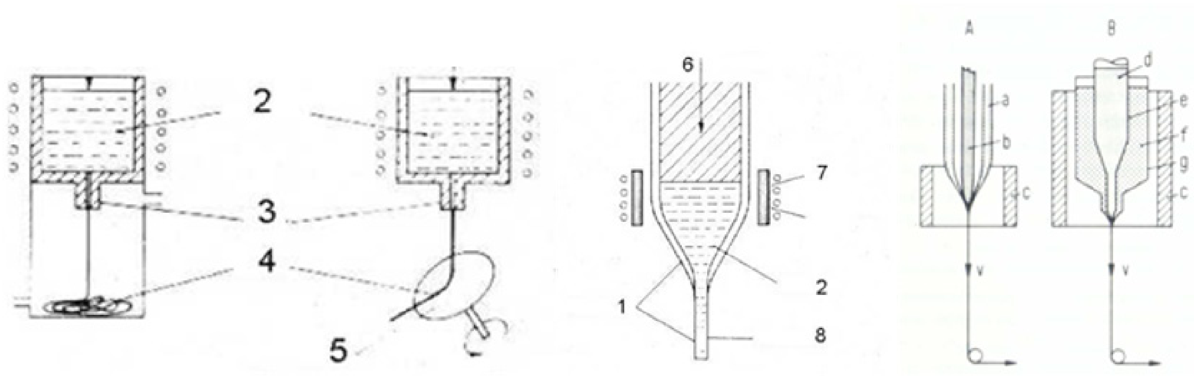

Figure 8: Deformation in the liquid state by induction and Taylor's method. Legend: 1-glass shell, 2-melt, 3-nozzle, 4-fiber, 5-cooling disc, 6-output rod, 7-induction heating coil, 8-microfiber, a-glass tube, b-glass rod, c-furnace, d-melt-core, e-inner crucible, f-melt-shell, g-outer crucible (tigel).

The deposition rate is 2-3 µm/s, and the thickness of the resulting layer - about 40 µm. Figure 7 shows a schematic diagram of the operation. Deformation in the liquid state can be carried out by the method of leakage of melt through a nozzle and by the method of Taylor [8-11]. The melting of the material is carried out by induction. Figure 8 illustrates the production of fiber by deformation in the liquid state. On the right are the basic schemes for the production of a glass-core and glass-shell light guide by the rod-tube method (A) and by the double crucible method (B). The difference is that in method (B) both types of glass are melted in separate crucibles before being drawn simultaneously through a concentric double nozzle [13,15].

Application: Phase-bonded composites are used as materials in details with superconductivity (NbTi, NbZr, Nb_3Sn in copper, bearing structures) and reinforcing materials in aircraft and rocketry, in light and protective structures, sports equipment. The production of contacts from phase-connected materials is carried out by plastic deformation in presses or hammers depending on the percentage of nickel in the material (Ag-Ni 20, Nimonic 80A). Figure 9 shows the sequences of work and deformation of the material in both variants (in presses - on the left).

Especially the asbestos-cement composite (asbestos cement), discovered in 1900 by the Austrian L. Hachek, became especially popular in the production of asbestos cement pipes, but due to its carcinogenicity it was stopped and replaced by materials such as Dolanit (Hoechst AG Germany) and Kuralon (company Kuraray Japan), produced on the basis of polyacrylonitrile. However, complete replacement of asbestos remains impossible.

Phase-bound composites are also used for the production of clutch and brake pads in the automotive industry, as well as in the household for flowerpots and various containers. Figure 9. on the right shows examples of fabrication of wear-resistant microstructures such as turbine blades, drive parts and in-vehicle closing mechanisms. Very popular are the Kevlar-29 and Rayon composites, which allow the production of fabrics of desired length. Phase-connected composites with "physiological" properties in medicine and biotechnology, combined optoelectronic microsystems with various purposes, neural networks for artificial intelligence, etc. are currently being implemented. Examples - [16,17].

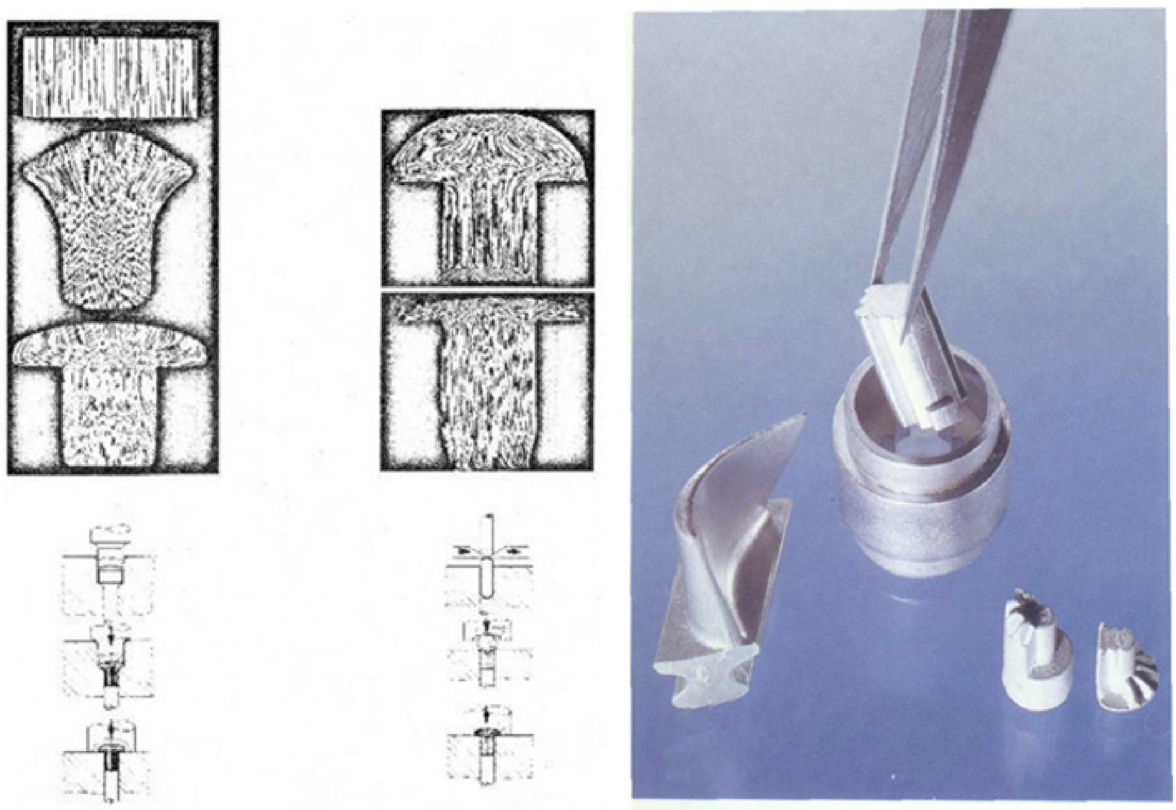

Figure 9: Technological process for microcontact and wear-resistant structures of phase-connected materials.

Conclusion

A classification of phase-bound materials is made, their properties are determined and methods for obtaining the charge (shihte). They are considered to be species technological processes for production of phase-connected materials. Special attention is paid to their application with an emphasis in mechatronics.

Acknowledgement

None.

Conflict of Interest

No conflict of interest.

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